Development of a II-VI-Based High Performance, High Band Gap Device for Thin-Film Tandem Solar Cells

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ABSTRACT

Development of the high efficiencies that can only be attained by tandem structures is important to the advancement of thin-film technologies. Although significant progress has been made with low and mid band gap polycrystalline devices, there is no viable high band gap device to pair with these in a tandem structure. We propose development of a high efficiency, high band gap device from the II-VI family for this purpose. To achieve a target efficiency of 25%, the high band gap device efficiency will have to be in the 16 – 18% range, and it will have to successfully transmit long wavelength light to an underlying low band gap device. Candidate II-VI materials include CdSe and $Zn_x Cd_{1-x} Te$. The initial structure will be 4-terminal to avoid issues associated with growing devices on top of each other in 2-terminal format. We have used AMPS to simulate expected performance.

1. Introduction

The ideal band gaps for optimum efficiency in a tandem structure are about 1 eV for the bottom cell and 1.7 eV for the top cell. Cu $In_xGa_{1-x}Se_2$ (CIGS) has already demonstrated a well established efficiency of 15% for a band gap of about 1 eV, and industry is presently commercializing products using this technology. Low band gap CIGS is thus an obvious choice for the bottom cell. Identifying a viable candidate for the top cell is much more difficult, and in fact is the crux of what needs to be done to launch a 25% tandem technology. Since about 2/3rds of the output must come from the top cell in a dual tandem, this requires a top cell efficiency of 16 – 18%.

II-VI materials have the required properties to achieve this objective. As seen in figure 1 Cd and Zn compounds offer options for the high Eg cell. An obvious choice is CdSe because it has an ideal Eg of 1.7 eV and is a binary. However, $Cd_xZn_{1-x}Te$(CZT) is perhaps a better option because it is to first order just an extension of the more familiar CdTe. As seen in figure 1, these compounds cover the Eg range 1.45 – 2.2 eV. While they have the added complexities of ternaries, they also offer the flexibility of tuning the band gap to the bottom cell. We have worked with these compounds in the past and made some progress in understanding and advancing their performance[1].

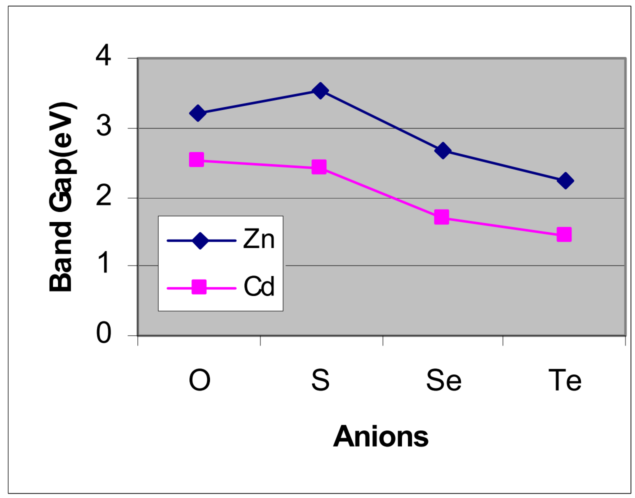

Figure 1. II-VI band gaps.

However, much of this work was shelved because of the success that we enjoyed with CdTe itself. Given the progress that has been made with single junctions and the mandate for a 25% tandem technology it is now appropriate to rejuvenate our earlier efforts on these promising materials.

2. Device Structure

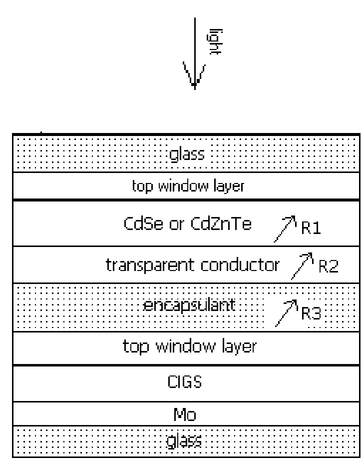

Figure 2. 4-terminal device structure.

Because of the inherent difficulties with growing materials on top of each other in a 2-terminal structure we propose the 4-terminal structure shown in figure 2. This is a schematic of the final 4-terminal structure that results from combining a top cell on glass to a bottom cell on glass with an encapsulant. The bottom cell is a low Eg CIGS device that has the same structure as today's standard devices. Thus the bottom cell is a given. It requires little or no further development, although additional tweaking to fit this role can contribute to more output. The top high Eg cell is what is needed and is the main topic of this project.

Optical issues associated with this multi-layer stack can be complex. As in any solar cell we always endeavor to capture as much incident light as possible. Thus the optical issues for the top of the high band gap cell are simply to tune AR coatings as usual but with an eye to the bottom cell as well. The additional issues have to do with effectively coupling light not used by the top cell to the bottom cell. Because the bottom cell reaches out into the near IR, absorption losses in the three transparent conductors(TC)(top window layer-top cell, rear transparent conductor-top cell, and top window layer-bottom cell) due to free carriers are a concern. However, currents are lower in tandem devices which allows for thinner TC's. We have had an ongoing effort to develop high optical quality TC's for some time, and those results can be brought to bear on this problem. We have performed first order simulations on optical losses and feel that the loss to the bottom cell can be kept down to about 10%.

3. 4-Terminal Efficiency Projections

CIGS is the assumed low band gap CIGS device. Several laboratories have achieved efficiencies in the 15% range for band gaps of about 1.0 eV. We have in fact found that this band gap range provides the highest efficiencies for our manufacturing-friendly processing approach and have developed considerable expertise with low band gap CIGS materials. We use the Penn State/EPRI AMPS code as a regular tool to simulate and help understand our material and device performance as well as to guide our fabrication efforts[2]. It is thus straightforward for us to extend our AMPS capabilities to tandem simulations. The representative parameters that we use for CIGS are Jsc = 42.6 mA/cm^2, Voc = 508 mV, FF = 0.68, and efficiency =14.7%. In figure 3 we show Jsc and efficiency for CIGS under a 1.7 eV top cell as a function of top cell thickness. As can be seen, there is a large drop under a 200 nm top cell, but additional losses are minimal as the thickness of the top cell is further increased. Voc and FF vary little with thickness, and the slow drop of Jsc allows an efficiency of 8-9% across the entire thickness range.

To simulate tandem output we assume an ideal top cell that has few loss mechanisms. In figure 4 the individual cell efficiencies and resulting tandem composite efficiency are plotted as a function of the top absorber thickness. The bottom line is that tandem efficiencies well above 25% are projected for the entire thickness range. Although this is a "semi-ideal" case, it is nevertheless highly encouraging. When we use realistic values for the top cell parameters, the projected peak efficiency is 25%, right at the desired objective. The challenge now is to make devices with these properties.

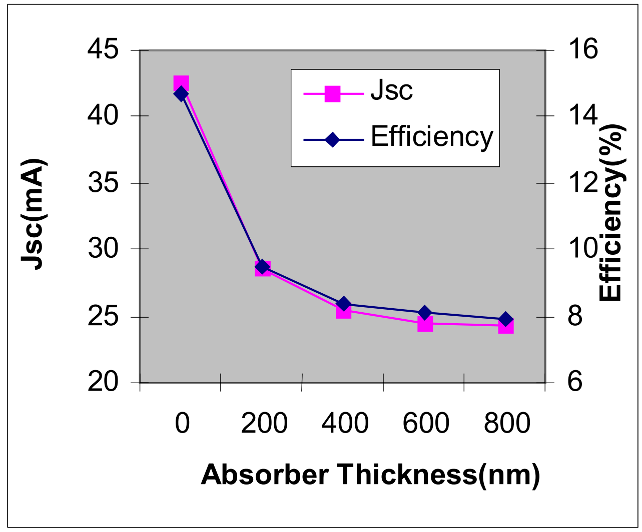

Figure 3 Jsc and efficiency for stand-alone CIGS and CIGS under a top 1.7 eV absorber cell of thickness 200-800 nm.

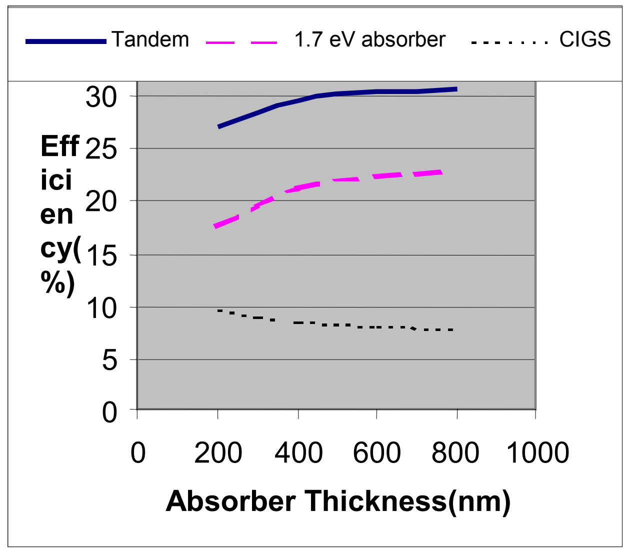

Figure 4 Tandem efficiency projections for an ideal 1.7 eV absorber top and standard CIGS bottom cell.

4. References

1. T. Chu, S. Chu, C. Ferekides and J. Britt, *J. Appl. Phys.*, **71**(11), 5635 (1992).
2. P. Panse, H. Sankaranarayanan, R. Narayanaswamy, M. Shankaradas, Y. Ying, C. S. Ferekides and D. L. Morel, Proceedings of the 28th IEEE PVSC, Anchorage, 09/2000.